HIGH RESOLUTION MEASUREMENTS OF SOLAR FLARE ISOTOPES

R. A. Mewaldt, J. D. Spalding, E. C. Stone, and R. E. Vogt
California Institute of Technology
Pasadena, California, 91125
U.S.A.

ABSTRACT

The individual isotopes of C, N and O have been measured in the large solar particle event of 9/23/78, and found to be consistent with solar system abundances. These observations, and previously reported measurements of Ne and Mg isotopes, allow us to investigate the possibility of mass dependent selection effects in this solar flare. The absence of any observable fractionation for C, O and Mg leads to the conclusion that solar neon is most likely neon-A with $^{22}Ne/^{20}Ne = 0.12$.

1. Introduction

The isotopic composition of the Sun is of interest to several fields of scientific investigation, among which are studies of the origin of the elements and studies of the formation of the solar system. Although the Sun is the major reservoir of solar system material, most of our present knowledge about the solar system isotope composition comes from the study of terrestrial material and meteorites, which by weight are trace constituents of the solar system. The solar wind and solar energetic particles provide direct samples of material from the solar atmosphere.

Neon isotope measurements of solar energetic particles (hereafter SEPs) have been previously reported by Dietrich and Simpson (1979) and Mewaldt et al. (1979), who found that the composition of SEPs was consistent with the meteoritic component neon-A which has $^{22}Ne/^{20}Ne = 0.121$, but not with measurements of the solar wind as reported by Geiss (1973), which gave $^{22}Ne/^{20}Ne = 0.073$. Mewaldt et al. (1979) concluded that there was only a 1% probability that their solar flare neon measurement ($^{22}Ne/^{20}Ne = 0.13\ +.04,\ -.03$) was consistent with the solar wind composition. This suggests the possibility of mass fractionation in either the solar wind or the SEP acceleration or propagation processes.

Mewaldt et al. (1981) also measured the magnesium isotope abundances in the 9/23/78 flare and found them to be consistent with meteoritic and terrestrial abundances, as well as the abundances observed in sunspots (see also Dietrich and Simpson, 1980). Using our measurements of C, N, O and Mg isotopes, we place limits on mass dependent selection effects occuring in the 9/23/78 solar flare by fitting a simple mass fractionation law to the data, and thereby relate the SEP composition more directly to the composition of the Sun.

2. Observations

The observations were made with the Caltech Heavy Isotope Spectrometer Telescope (Hist) on ISEE-3 (Althouse et al. 1978). The measurements of C, N and O isotopes use similar techniques to those used for our neon observations (Mewaldt et al. 1979). Up to three independent

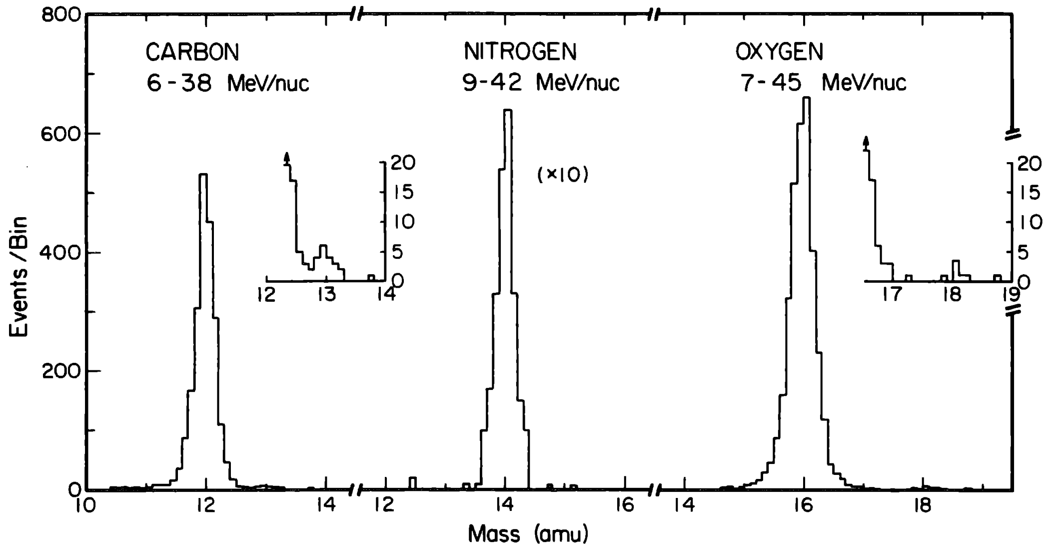

Figure 1 - Mass histograms for C, N and O observations. In the nitrogen histogram there are 2 events near ^{15}N.

estimates of each particle's mass were made using the multiple dE-dX vs. residual energy method. These estimates were then intercompared for self-consistency, and a final best estimate obtained from a weighted average of the individual mass determinations.

Mass histograms of the accepted events are shown in Figure 1. This is the first time that the isotopes ^{13}C and ^{18}O have been resolved in measurements of SEPs. The observed standard deviations for the mass estimates, obtained by fitting Gaussian peak shapes to the mass histograms in Figure 1 are 0.175 amu for carbon, 0.161 amu for nitrogen and 0.212 amu for oxygen.

The results of our observations are listed in Table 1. The uncertainties on the abundances in Table 1 include both statistical uncertainties, computed using the maximum likelihood method, and upper limits on systematic uncertainties, due to possible background at the

Table 1
Isotope ratios, 9/23/78 solar flare

Isotope Ratio	Energy Interval (Mev/nuc)	Observed Ratio	Solar System (Cameron 1980)
$^{13}C/^{12}C$	6-38	$0.010^{+.003}_{-.004}$	0.0112
$^{14}C/^{12}C$	6-38	< 0.0014	radioactive
$^{15}N/^{14}N$	9-42	$0.008^{+.010}_{-.005}$	0.0037
$^{17}O/^{16}O$	7-45	< 0.0019	0.00037
$^{18}O/^{16}O$	7-45	$0.0018^{+.0007}_{-.0008}$	0.00204
$^{21}Ne/^{20}Ne$	11-26	< 0.016	0.0030
$^{22}Ne/^{20}Ne$	11-26	$0.13^{+.04}_{-.03}$	0.122
$^{25}Mg/^{24}Mg$	12-36	$0.14^{+.05}_{-.02}$	0.129
$^{26}Mg/^{24}Mg$	12-36	$0.15^{+.04}_{-.03}$	0.142

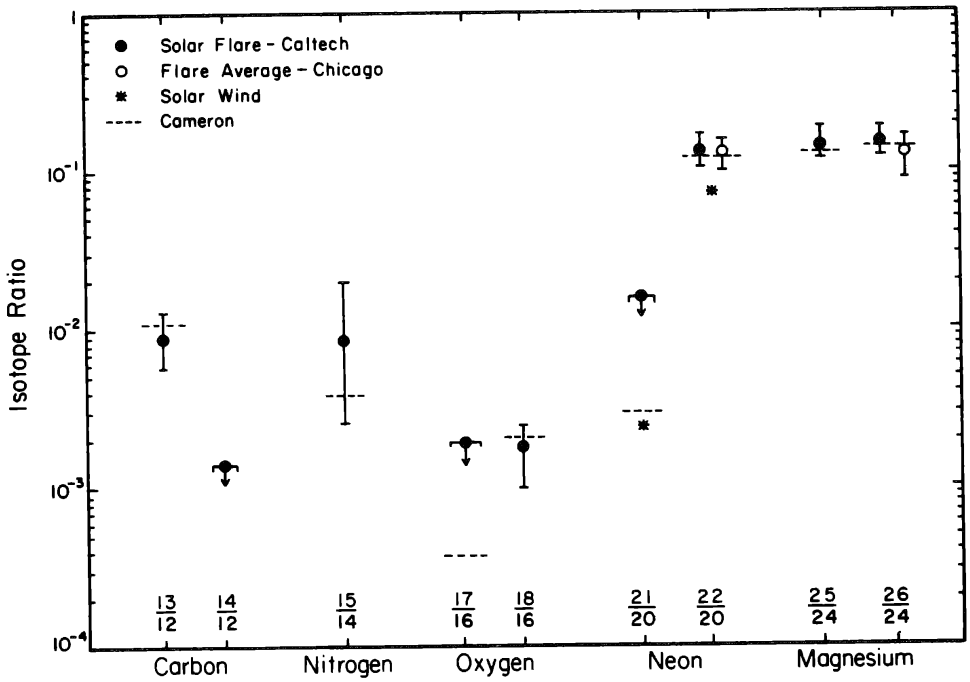

Figure 2 - Solar isotope abundance ratios.

location of the rare neutron-rich isotopes resulting from non-Gaussian tails on the distributions. Note that mechanisms which introduce signal loss in the energy measurements, such as nuclear interactions, detector edge effects or incomplete charge collection, cause a lower mass estimate. For example, we expect the background at ^{11}C to be higher than at ^{13}C due to this effect.

In Figure 2 we compare our results with solar system isotope abundance ratios (Cameron 1980), solar wind measurements (Geiss 1973), and with measurements of SEPs by Dietrich and Simpson (1979, 1980), who averaged the data from several solar events. Note the excellent agreement of the solar flare results with the Cameron abundances.

3. Discussion

For neon, observations of SEPs with $^{22}Ne/^{20}Ne = 0.131$ and solar wind measurements with $^{22}Ne/^{20}Ne = 0.073$ show the Sun to be emitting two different isotopic components. In order to investigate the possibility that mass fractionation in the solar flare acceleration or propagation processes may be the origin of this apparent discrepancy, we derive a reduced abundance ratio by dividing the SEP abundance ratio by the solar system abundance ratio (Cameron 1980). The bottom panel of Figure 3 is a plot of this reduced ratio vs. the ratio of the isotopic masses A_j/A_i, where j is the heavier isotope. The top panel of Figure 3 is identical except that the solar wind isotopic abundance ratio was substituted for the Cameron value. Isotopic variations are also observed in solar system material for the elements C, N, O and Mg, but our data are not precise enough to allow an investigation analogous to that for neon.

A simple possibility for mass fractionation during the solar flare acceleration or propagation processes would be a linear fractionation law, with the change of the abundance ratio for the two isotopes of the same element proportional to the ratio of their masses. If $\zeta(j,i)$ is the enhancement factor and α the constant of proportionality, $\zeta(j,i) = \alpha\ ((Aj/Ai)-1)$. Fitting this to the reduced isotope ratios $^{25}Mg/^{24}Mg$, $^{26}Mg/^{24}Mg$, $^{18}O/^{16}O$ and $^{13}C/^{12}C$ yields $\alpha = -0.3 \pm 1.9$. The resulting mass fractionation law predicts a change $\zeta(22,20) = -0.03 \pm 0.19$ in the reduced abundance ratio for $^{22}Ne/^{20}Ne$. Considering this mass fractionation value and its errors, the observations reported in Mewaldt et al. (1979) remain inconsistent with a solar wind neon composition for the Sun at the 97% confidence level.

Thus, our data are consistent with the absence of significant mass fractionation in SEPs from origin to observation. A remaining possibility is that solar neon is neon-A, and that fractionation occurs in the solar wind acceleration process, with preferential escape of ^{20}Ne from the Sun.

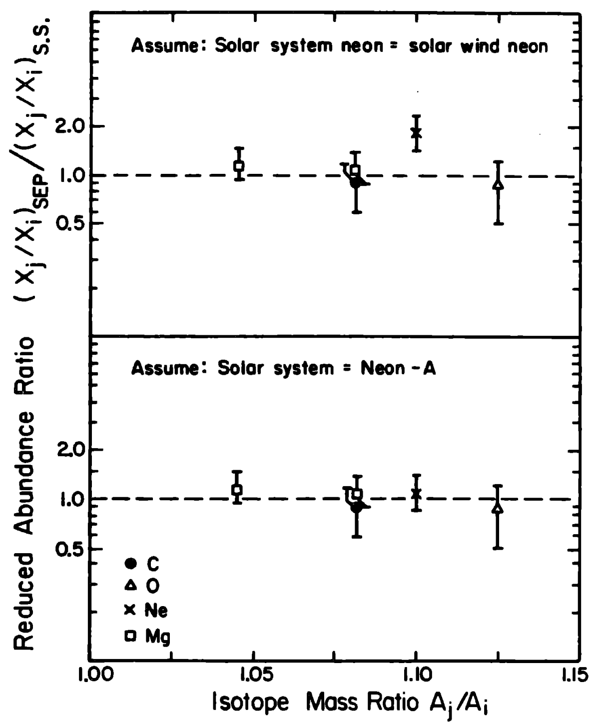

Figure 3 - (top panel) Reduced ratio with solar wind neon.
(bottom panel) Reduced ratio with neon-A.

Acknowledgements: This work was supported in part by NASA under contract NAS5-20721 and grant NGR 05-002-160.

References

Althouse, W.E., Cummings, A.C., Garrard, T.L., Mewaldt, R.A., Stone, E.C., and Vogt, R.E. 1978, Geoscience Electronics, 16, 204.

Cameron, A.G.W. 1980, Harvard University, Center for Astrophysics, preprint No. 1357.

Dietrich, W.F. and Simpson, J.A. 1979, Ap. J. (Letters), 231, L91.

Dietrich, W.F. and Simpson, J.A. 1980, University of Chicago, preprint.

Geiss, J. 1973, 13th Internat. Cosmic Ray Conf. (Denver: University of Denver), 5, 3375.

Mewaldt, R.A., Spalding, J.D., Stone, E.C., and Vogt, R.E. 1979, Ap. J. (Letters), 231, L97.

Mewaldt, R.A., Spalding, J.D., Stone, E.C., and Vogt, R.E. 1981, Ap. J. (Letters), 243, L68.